Life History of a Coastal Plain Population of the Mottled Sculpin, *Cottus bairdi* (Osteichthyes: Cottidae), in Delaware

FRED C. ROHDE

Charles T. Main, Inc.,

Prudential Center, Boston, Massachusetts 02199

AND

RUDOLF G. ARNDT

Faculty of Natural Sciences and Mathematics,

Stockton State College, Pomona, New Jersey 08240

ABSTRACT.— Aspects of the biology of a Coastal Plain population of *Cottus bairdi* in a lowland forest stream in Delaware were examined during 1973-81. *Cottus bairdi* occurs primarily over a gravel substrate; naturally-occurring rocks are absent. Individuals are shorter-lived and attain sexual maturity at a smaller size than in other studied populations. Two age groups, and a presumed third, were found. Only 33% of age group 0 survives to spawn in age group I. Spawning occurs in February and March at a water temperature of 6.5° to 12.5° C, and mean ovum diameter is 2.15 mm. There is a strong relationship between ova number and standard length (Y = -157.11 + 6.80 SL). Fecundity is lower than that reported for most populations of *C. bairdi.* Most eggs are deposited in single-spawn clusters, with a mean egg number of 134.2 per cluster. Condition factor indicates that males are generally more robust than females. Most growth in length occurs in age group 0, males are longer than females, and there is a highly significant difference in sex ratio of mature specimens taken.

Dominant food is trichopteran and dipteran larvae, and plecopteran nymphs; crustaceans, ephemeropteran nymphs, and coleopteran larvae are of minor importance. There is seasonal variation in food items. Diet differs only slightly as a function of sculpin size.

INTRODUCTION

The mottled sculpin, *Cottus bairdi*, is widely distributed in the United States and Canada (Lee 1980) and there are numerous studies of aspects of its life history (Gage 1878; Smith 1922; Hann 1927; Koster 1936, 1937; Bailey 1952; Daiber 1956; Ludwig and Norden 1969; Patten 1971; Nagel 1980). There are, however, only four known Atlantic Coastal Plain populations, all located in the Nanticoke River system, Chesapeake Bay drainage. We studied one of these, in Butler Mill Branch and its tributaries, near Seaford, Sussex County, Delaware, during 1973-75 and 1978-81 and report here on habitat, reproduction, age and growth, food habits, and abundance. Franz and Lee (1976) reported on a population in Caroline County on the Eastern Shore of Maryland, 4.0 km north of Federalsburg and 15.2 km northwest of Butler Mill Branch, and briefly considered habitat, food habits, and size. In spring 1981 we discovered a third population, in upper Sullivan Branch and the lower parts of its tributaries, Wolfpit and Raccoon branches, 6.4 km north of Federalsburg, Caroline County, Maryland, and a fourth in Skinners Run, at a point just upstream of Route 307 and 4.0 km southwest of Federalsburg, Dorchester County, Maryland. All data herein refer to the Butler Mill Branch population, unless otherwise specified.

MATERIALS AND METHODS

Specimens of *C. bairdi* (N = 1009) were collected with a 3.0 m × 1.2 m, 3.2 mm mesh nylon flat seine. All habitats were sampled. Collections were made on 28 October and 4 November 1973; 20 January, 17 February, 17 March, 20 July, 8 September and 30 November 1974; 2 and 23 March 1975; 7 September and 26 November 1978; 16 March and 25 July 1979; 9, 15, 22 and 30 March, 13 April, 4 and 20 May, 8 and 28 June, 12 and 25 July, and 9 August 1980; and 22 and 27 February, 7, 14, 22, 26 and 29 March, 5, 11, 18 and 25 April, and 19 May 1981, between 1050 and 2000 hours. Fish were preserved in 10% formalin and stored in 40% isopropyl alcohol until examined. For conservation purposes, the last specimens taken in each collection, regardless of sex, size, and reproductive condition, were usually released. Through 1979, only relatively small samples were taken, because of the presumed small size of the population. Sampling was intensified in 1980 and 1981 to pinpoint spawning time, locate eggs, and collect larvae. In 1981, fish were primarily observed in the field, and most of those collected were released alive.

An additional 41 adult *C. bairdi* were taken by seine in spring 1981 at the new Caroline County locality, 6 adults at the Dorchester County locality, and 1 adult at the locality given by Franz and Lee (1976); these were preserved.

Air and water temperature, pH (Hach Kit), and dissolved oxygen (Yellow Springs meter) were recorded at time of capture. To help characterize the habitat in areas particularly frequented by *C. bairdi*, semiquantitative substrate samples of about 8 liters were taken from Butler Mill Branch and about 1.2 liters from an upper tributary. The samples were dried and sieved, and the percentage by weight of several gravel/sand particle size categories determined.

Gonadal development was determined by calculating the gonosomatic ratio (gonad weight as a percentage of total weight) of 235 females and 121 males taken during 1973-80. This sample included only sculpins that could be sexed and with gonads of 0.001 g or heavier (young-of-the-year from September, October, and November collections, and all adults). Gonads were weighed to the nearest 0.001 g. Fecundity of 67 pre-spawning females collected in January (20) and February (3) 1973, March (10) 1979, and March (34) 1980 was determined. Ten ova from each of 57 mature females were measured to the nearest 0.1 mm using an ocular micrometer, and the ova growth rate determined. Deviation from a 1:1 ratio of ova number between right and left ovary in 22 fish was tested with chi-square, as was deviation from a 1:1 sex ratio. Standard length (SL) and total length (TL) were measured to the nearest mm and total body weight to the nearest 0.01 g.

Eggs were collected where adults were most common. Pieces of concrete block, bricks, and water-logged wood suitable as egg attachment sites were provided on 9 March 1980 and 22 February 1981. Color was recorded on live eggs; other data are from preserved eggs. Attempts to collect larvae with a fine-mesh dip net and a 0.5 mm plankton net were made in the same area.

Age was determined by the length-frequency method. Although otoliths have been used to determine age in sculpins (Koster 1936: Ludwig and Norden 1969; Patten 1971; Petrosky and Waters 1975), our results using otoliths from both fresh and preserved *C. bairdi* were inconclusive. The relationship between growth in weight and in length for specimens that could be sexed was determined by fitting a regression line on the logarithms of mean weights and SL for 3 mm intervals. Fitness was determined with the coefficient of condition (K) using the formula $K = \frac{W \times 10^5}{L^3}$, where W is weight (g) and L is SL (mm).

Based on examination of 539 stomachs, we determined the number of food items in five fish SL groups ($<$20 mm, 20-29 mm, 30-39 mm, 40-49 mm, $>$49 mm), and the percent occurrence of food by month.

Voucher specimens from all localities were deposited in the Academy of Natural Sciences of Philadelphia (ANSP 145647, 145648, and others), and specimens from the Butler Mill Branch locality were also deposited at Iowa State University (ISU 1995, 1996), and the University of Florida (UF 30136, 30137).

STUDY AREA

The Butler Mill Branch system lies between 8 km northwest and 4 km southwest of Seaford, Sussex County, Delaware. It consists of Horse

Pen, Green Briar, and Butler Mill branches, and several unnamed tributaries. Its maximum length is 10.5 km (9.0 km straight-line) and its area 23.8 km^2. The creeks are bordered by mature lowland forest of red maple, *Acer rubrum;* American holly, *Ilex opaca;* green ash, *Fraxinus pennsylvanica;* tulip tree, *Liriodendron tulipifera;* sweetgum, *Liquidamber styraciflua;* black tupelo, *Nyssa sylvatica;* and sweetbay, *Magnolia virginiana;* some upper parts, however, pass through agricultural fields.

In the upper system the dominant creek substrate is mud and mud-sand, and typical stream width and depth in spring are 1 m or less, and some 20 cm, respectively. Gravel patches appear downstream and become more common lower in the system. Greatest stream width is 7 m, at a point below an impoundment (Craigs Pond) on lower Butler Mill Branch. The uppermost waterways sometimes dry completely, and areas just downstream of these form pools. Current and flow in the lower system are strong all year. Storms often cause local creekside flooding. Aquatic vegetation, consisting of several vascular species and filamentous green algae, is local and often luxuriant. Rocks, usually prominent in *C. bairdi* habitat, are absent.

Cottus bairdi is found only in areas of permanent and pronounced flow (Fig. 1). In its upstream distribution, *C. bairdi* is found only over gravel patches, where concomitantly there is a stronger current. Creek width here is often only 1 m, with depths to 5 cm. Patches are typically about 1 m long and 0.3 m wide, comprised of fine gravel and sand, and located several dozen meters apart. *Cottus bairdi* occurs but sparingly on these patches. Gravel patches and *C. bairdi* are both progressively more common farther downstream in Horse Pen, Green Briar, and Butler Mill branches. *Cottus bairdi* is not found below or just above Craigs Pond, although prior to impoundment it likely did occur in both areas.

All preserved specimens and related data, unless otherwise specified, were collected in a sampling area located in the downstream part of the study area (Fig. 1), over and near two large and easily accessible gravel riffles (of 4.6 m × 6.5 m and 4.6 m × 28.0 m). The strongly meandering stream here is 4 to 5 m wide, with a substrate of alternating gravel riffles, mud-bottom pools, and sand. The riffles are several cm deep, the pools to 1.2 m, and sand occurs at intermediate depths. The banks are steep and frequently undercut, with masses of exposed fine tree roots. The south bank abuts lawns behind homes, and the north side is mostly forested. Concrete block riprap has been placed along the developed shore to prevent erosion. Dominant aquatic vegetation is pondweed, *Potamogeton* sp.; water starwort, *Callitriche palustris*; water purslane, *Ludwigia palustris*; bur reed, *Sparganium* sp.; and unidentified filamentous green algae. Vegetation occurs primarily in cleared, sunlit areas near the homes and highway. *Cottus bairdi* is abundant throughout. The water, usually

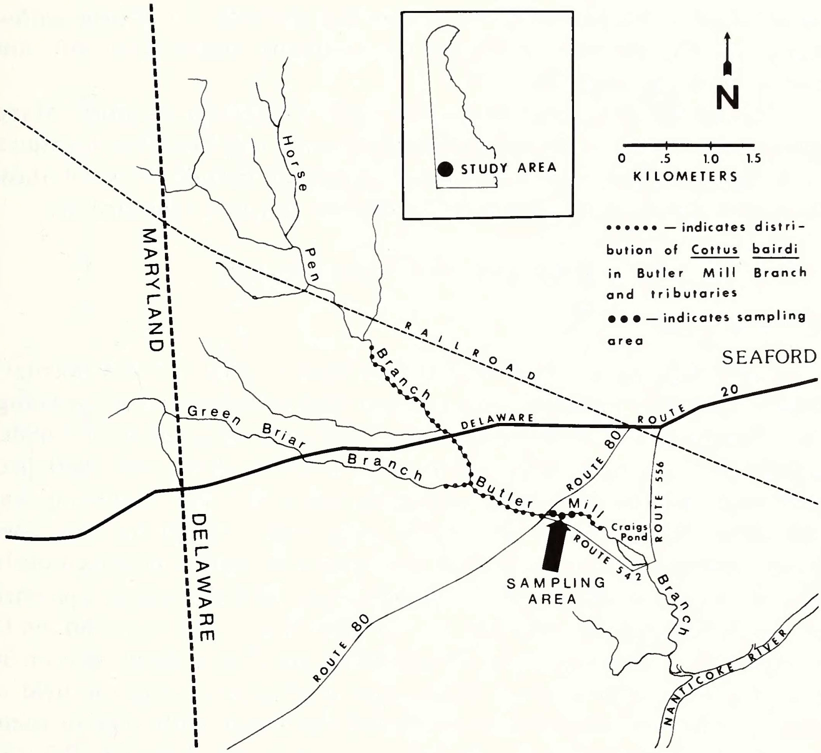

Fig. 1. The Butler Mill Branch system near Seaford, Sussex County, Delaware, showing *Cottus bairdi* distribution and sampling area.

clear, is turbid after rain. Temperature in the sampling area ranged from 5.5° C (February) to 20.0° C (July), pH from 5.7 to 7.0 (typically 6.5), and dissolved oxygen concentrations from 9.1 to 12.8 ppm.

Stream flow data were taken in the sampling area on 22 dates between 30 June 1955 and 16 April 1969 by the U.S.D.I. Geological Survey, Water Resources Division (Robert H. Simmons, pers. comm.) at low-flow conditions (after periods of no rain for four or five days). Average stream cross-section area was 0.76 m^2 (range 0.20-2.17), mean flow 0.16 m^3/sec (0.04-0.46), and mean water velocity 0.21 m/sec (0.10-0.29). The lowest values were from summer, the highest from spring and late fall.

Fifteen fishes were taken with *C. bairdi* (number of times in parentheses) in a total of 26 collections made in the sampling area during 1973-80: *Lampetra aepyptera* (20), *Anguilla rostrata* (18), *Umbra pygmaea* (11), *Esox americanus* (1), *Esox niger* (6), *Notemigonus crysoleucas* (4), *Erimyzon oblongus* (17), *Ictalurus natalis* (2), *Ictalurus nebulosus* (1), *Aphredoderus sayanus* (10), *Acantharchus pomotis* (1), *Enneacanthus gloriosus* (3), *Lepomis gibbosus* (5), *Lepomis macrochirus* (6), and *Etheostoma olmstedi* (26).

Cottus bairdi habitat in Caroline and Dorchester counties, Maryland, including physicochemical characteristics, is as described for Butler Mill Branch. Maryland fish species-associates include some of those listed previously, plus *Etheostoma fusiforme* and *Perca flavescens*.

RESULTS AND DISCUSSION

Reproduction

Spawning occurs in February and March. Two females taken 17 March 1974 each contained only two ova, indicating the end of spawning. On 2 March 1975, 1 of 31 females was spent and, although other females contained ova, there were fewer than in 1974, 1979, and 1980 prespawning samples, indicating spawning was under way. Spawning was completed by 23 March; all ovaries were empty except for some ova being resorbed. Spawning in 1979 was later, and females collected on 16 March still possessed a full ova complement. In 1980 females spawned primarily between 9 and 22 March: on 9 March none had spawned, on 15 March 2 of 22 were spent, by 22 March all but 1 were spent, and on 30 March all taken were spent. Examination of specimens in the field in 1981 yielded the following ratios of females heavy with eggs to spent females: 22 February, 13:1; 27 February, 10:2; and 7 March, 7:3. On subsequent dates all taken had completed spawning.

February and March spawning is generally earlier than that reported for *C. bairdi.* Other reports based on direct (deposited eggs) or indirect (mature ova or specimens in breeding condition) evidence are: Nagel (1980), Tennessee, early April; Ludwig and Norden (1969), Wisconsin, 1 April to 3 May; Ricker (1934), Ontario, middle of May; Bailey (1952), Montana, most of June; Gage (1878), New York, April; Koster (1936), New York, April to June; Smith (1922), Michigan, April and May; Robins (1954), Appalachian region, late March to early May. Pflieger (1975) found presumed *C. bairdi* eggs in Ozark streams from early November to late February. William L. Pflieger (pers. comm.) has confirmed records of eyed eggs from 2 February 1971 and of males guarding egg masses with embryos far enough advanced to show movement on 23 and 29 February 1971, which indicates spawning occurred at least as early as January. This early spawning, however, may not be attributable to *C. bairdi*, as most Ozark populations are considered to represent an undescribed species.

Ovary weight as a measure of gonad development during 1973-75 was low in October and November 1973, increased rapidly in January, and peaked in February 1974 (Fig. 2, Table 1). The gonosomatic ratio

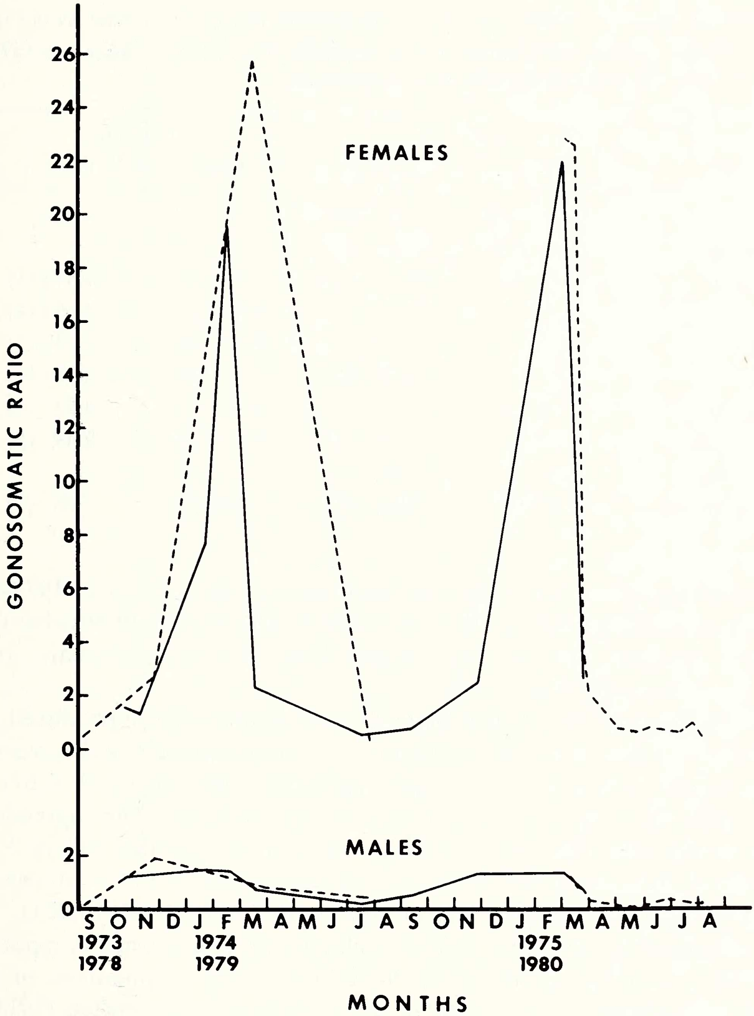

Fig. 2. Relationship between gonad weight and body weight in male and female *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, October 1973-March 1975 (solid lines) and September 1978-August 1980 (broken lines).

dropped markedly in March 1974, at spawning, was low through summer, and increased again in November. The maximum value was reached early in March 1975, and was followed rapidly in mid-March by another sharp post-spawning decrease. The gonosomatic ratio pattern for males was similar to that for females, but monthly differences were not as pronounced (Fig. 2, Table 1). Maximum development in 1974 was in January, followed by a summer decline and a fall increase, and values

Table 1. Average combined monthly gonosomatic ratios (expressed as %) for *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, 1973-1980. Number of specimens in parentheses.

Month	1973-75 Male	1973-75 Female	1978-80 Male	1978-80 Female
January	1.52 (4)	7.57 (20)		
February	1.40 (2)	19.51 (3)		
March	1.05 (15)	20.73 (33)	0.85 (35)	16.51 (71)
May			0.09 (3)	0.65 (14)
June			0.09 (5)	0.74 (17)
July	0.21 (5)	0.57 (14)	0.16 (6)	0.56 (13)
August			0.20 (1)	0.53 (1)
September	0.53 (3)	0.71 (14)	0.16 (14)	0.49 (5)
October	1.21 (7)	1.46 (4)		
November	1.26 (17)	2.18 (25)	1.94 (4)	2.68 (1)

remained high from November through March. Both sexes in 1978-80 showed patterns similar to those of 1973-75. The March 1979 value for females, however, was markedly higher than that of other years, and reflects a later spawning in 1979.

Fecundity, a general term that refers to number of ova produced, is restricted in this study to the number of mature ova present in the ovaries from January to mid-March. Mean ova number per female (N = 67) is 93.7 (range 37-156), and mean female SL is 36.9 mm. The regression equation for the relationship between SL and ova number (Y) is: $Y = -157.11 + 6.80\ SL$ (Fig. 3). The correlation coefficient, $r = 0.90$, indicates a strong positive relationship between ova number and SL ($P < 0.001$).

Fecundity of the Butler Mill Branch sculpins is low when compared with data for other species of *Cottus* and for other populations of *C. bairdi* in Williams (1968), Ludwig and Norden (1969), Patten (1971), Foltz (1976), and Nagel (1980). Exceptions are the diminutive *C. pygmaeus*, with a range of 30 to 43 ova (Williams 1968), and *C. bairdi* from northeastern Tennessee with means of 55.5 to 67.7 ova (Nagel 1980). The low fecundity observed in our specimens and in *C. pygmaeus* is correlated with their small size, while in the Tennessee population it appears to be correlated with a greater ova size. Females taken in 1978-80 were more fecund ($Y = -209.87 + 8.13\ SL$) than in 1973-75 ($Y = -142.24 + 6.46\ SL$). This difference is significant (0.05 level, testing the slope), and may be a function of size. However, although females in 1978-80 were larger ($\bar{x}$ SL = 38.2 mm) than in 1973-75 ($\bar{x}$ SL = 34.5 mm), the difference of the means is not significant. Nagel (1980) noted a similar difference in fecundity

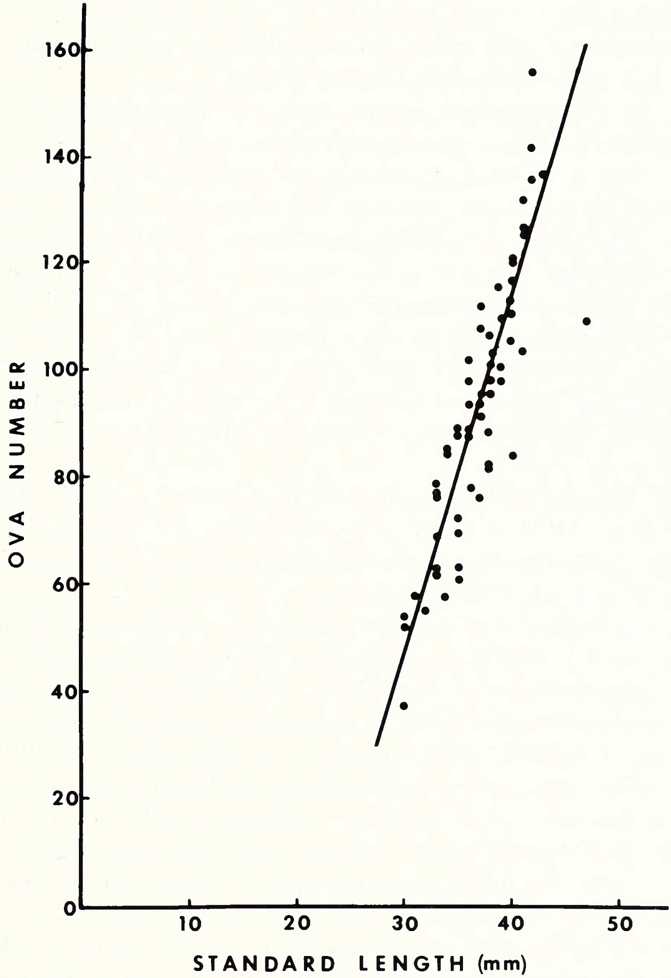

Fig. 3. Relationship between number of mature ova and standard length of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware.

between two sampling periods, in which there also was no significant difference in size of adults.

Hann (1927) generalized that fecundity in *C. bairdi* is approximately proportional to the cube of the female's length. This is in agreement with relationship, Log F = -2.738 + 2.962 Log SL, observed by Ludwig and Norden (1969) in Wisconsin. Their fecundity-length relationship is higher than that observed by us for all Butler Mill Branch females examined: Log F = -2.129 + 2.608 Log SL.

The regression equation for the relationship of ova number (Y) to body weight (W) is: Y = 49.19 + 31.43 W. The correlation coefficient of 0.77 is significant ($P < 0.001$), and indicates a positive relationship between ova number and gravid female weight.

Mature ova (large and orange) were not observed in 235 females until January. In 1974, mean diameter of ova from 14 preserved females increased from 1.18 mm in January to 2.07 mm just prior to spawning in March. The largest ovum measured 2.4 mm (early March). Values in 1975 (N = 23 females) fell within these ranges. In March 1980 (N = 20 females) the range was 1.8 to 2.5 mm ($\bar{x}$ = 2.15 mm). There was no difference in mean ovum diameter between ovaries (N = 22 females). Ludwig and Norden (1969) gave ova diameters of 1.50 to 2.06 mm ($\bar{x}$ = 1.88 mm) in Wisconsin, and Hann (1927) of 2 to 2.5 mm in Michigan. Nagel (1980) observed a larger average ovum size (3.32 mm) in Tennessee *C. bairdi* and suggested that it correlated with the smaller number of ova produced.

The relationship between diameter of mature ova and SL is significant ($r = 0.55$; $P < 0.01$). This is in agreement with Hoar (1957) who stated that mature ova size depends both on size of parent and on nutrition during the pre-spawning period.

In seven females, the right ovary was usually longer ($\bar{x}$ = 9.5 mm) and narrower ($\bar{x}$ = 4.2 mm) than the left ($\bar{x}$ = 8.7 and 5.0 mm, respectively). The right contained a mean of 41.2 ova, the left 39.9. There is no significant chi-square difference from the expected 1:1 ratio ($P > 0.05$).

A total of 2 egg clusters was found in 1980, and 37 in 1981. The larger number was due to additional egg attachment sites provided in February 1981, and to more extensive searching. In 1980, the first cluster was found on 15 March and the second on 22 March (deposited in the interim). In 1981, the first seven clusters were found on 27 February, five others on 7 March, and another six on 14 March. Additional clusters found on subsequent dates resulted (at least primarily) from searching in areas not examined earlier, rather than from later egg deposition. All clusters were found in and near two gravel riffles in the sampling area (Fig. 1), and to about 30 m upstream. All were in areas of fast current, usually near the stream center, and over gravel or gravel-sand substrate. Water depth by the eggs (on several dates in early 1980 and 1981) ranged from 3 to 50 cm ($\bar{x}$ = 20.0 cm, N = 40 measurements).

With one exception, every cluster was attached to the underside of a submerged object. The exception was in a hollow on the upper surface of a submerged log. One cluster was under a beer can and another under a bottle, and three others were under waterlogged wood: a branch, a piece of board, and a piece of cut log. Favored egg-attachment sites were pieces of concrete block and bricks, and 23 (58.9%) of the clusters were found on such objects. Ten clusters (25.6%) were on ironstone and silicified sandstone (both usually flat and concave beneath). Both occur naturally in this part of the Delmarva Peninsula, but the large local concentration was probably dumped there for old construction. Only two clusters (5.1%) were found on naturally-occurring material (log and branch). The general absence of rock or other suitable spawning sites in Delmarva Peninsula streams may limit *C. bairdi* distribution.

Four substrate samples from these two gravel riffles yielded particles that ranged in size from greater than 2.5 cm to smaller than 0.05 cm; about half the particles (by weight) were in the size category 0.8 to 2.5 cm (Table 2). By contrast, about half the particles (by weight) in three samples from three gravel patches in Horse Pen Branch were 0.05 cm or smaller (Table 2). The largest pieces of gravel collected in the sampling area riffles measured (maximum length and width, cm) 7.5 × 3.9, 6.1 × 3.5, and 5.9 × 4.2, while the largest from Horse Pen Branch were 2.2 × 1.7, 2.3 × 1.4, and 2.0 × 1.4. *Cottus bairdi* was much more common over the riffles of larger gravel, perhaps because under natural conditions these facilitate spawning.

We consider 32 of the 39 clusters to represent the spawn of 1 female, 3 the spawn of 2 females, and 4 the spawn of 3 females. Ludwig and Norden (1969) noted a mean of 3.3 spawns per cluster. Koster (1936) observed up to six clusters in a nest, but noted that most nests contained from one to four egg masses. Clusters resulting from multiple spawnings can be identified by their larger size, varied egg mass colors, and irregular configuration. There were four instances of two single spawns found under one piece of substrate (each cluster was counted as the spawn of one female), and several cases of single- and multiple-spawn clusters on substrate with multiple-spawn clusters. Thus, the result of a total of 50 spawnings was found, deposited on a total of 31 pieces of substrate.

Color of live eggs was usually pink-orange, but the range in color of clusters was from orange to yellow to tan, and one cluster was almost white. About half of the clusters contained one to several white eggs, presumed to be unfertilized. Most clusters were approximately circular in outline, with eggs arranged in irregular rows, usually to four or five layers deep. They adhered strongly to the substrate and to each other. Egg cluster mean length, width, and height, respectively, and the range of each (in mm), for the total sample sizes given previously were: single spawn, 24.8 (16-37), 20.6 (13-29), 8.1 (6-12); two spawns, 40.0 (28-45), 24.3 (22-26), 8.6 (7-10); and three spawns, 48.2 (40-56), 30.0 (28-32), 11.7 (8-19).

Egg number in 11 single-spawn clusters ranged from 64 to 201, with an egg diameter range (measured to nearest 0.1 mm) of 2.2 to 3.5 mm, and a mean egg diameter per cluster range of 2.32 to 3.09 mm; egg number for one triple-spawn cluster was 623, with a range in egg diameter

Table 2. Percentage weight means and ranges of different size categories of gravel-sand substrate from riffles in the Butler Mill Branch sampling area, and from patches in Horse Pen Branch, Sussex County, Delaware, 1980.

		Particle Size (cm)						
	% weight	≤0.05	>0.05	>0.1	>0.2	>0.4	>0.8	>2.5
Butler Mill Branch sampling area (N=4)	Means	9.7	6.7	6.1	7.2	14.0	49.6	6.7
	Ranges	3.5-14.3	3.8-8.9	3.6-8.7	5.6-9.5	10.2-17.3	41.4-54.2	9.0-10.9
Horse Pen Branch (N=3)	Means	46.8	18.7	14.4	12.6	6.4	1.1	-
	Ranges	45.3-48.6	14.7-20.7	11.2-17.8	11.0-14.2	5.4-7.2	0.3-1.7	-

of 2.5 to 3.4 mm, and a mean egg diameter of 2.87 mm (Table 3). Range in egg number was higher than that determined by examination of ova in females, as was the mean of 134.2 eggs (measured only for single-spawn clusters) versus 93.7 ova per female. These differences are not readily explained. Butler Mill Branch sculpin eggs are smaller in diameter than those found by Nagel (1980) in Tennessee ($\bar{x}$ = 3.73 mm). There was no relationship between egg diameter and date collected, or between egg diameter and cluster size.

Eggs preserved on the following dates were in the indicated stages of development: 27 February 1981, morula or earlier; 14 March 1981, morula and blastoderm; 15 March 1980, morula or earlier; 22 March 1981, morula or earlier (1 cluster), and with large, well-developed, curled embryos with large, black-pigmented eyes (3); 26 March 1981, with less well-developed young than the latter 22 March eggs, with large, gray eyes (1), and with well-developed young (1); and 29 March 1981, with well-developed young. Eggs in many clusters in the field on 22 March 1981 contained well-developed, active young. The number of eggs and clusters found with such advanced embryos increased on subsequent dates.

Eggs hatching in the field were first noted on 29 March 1981, when several empty egg shells were found in each of four clusters. Embryos in the remaining eggs were advanced and active. One cluster missing on this date may have totally hatched (rather than being destroyed by predators or high water). By 5 April 1981, all eggs in nine clusters had hatched, by

Table 3. Data on *Cottus bairdi* egg clusters collected in 1980 and 1981 at Butler Mill Branch, Sussex County, Delaware.

Date collected and preserved	N spawns/ cluster	N eggs/ cluster	Range egg diameter (mm)	$\bar{x}$ egg diameter (mm)	N eggs measured
27 February 1981	1	170	2.6 - 3.4	2.86	20
27 February 1981	1	201	2.5 - 2.9	2.66	20
14 March 1981	1	117	2.2 - 2.5	2.32	20
15 March 1980	1	133	2.2 - 2.5	2.33	30
22 March 1980	1	64	2.3 - 2.4	2.35	20
22 March 1981	1	119	2.6 - 2.9	2.77	20
22 March 1981	1	170	2.8 - 3.1	2.94	20
22 March 1981	1	126	2.7 - 3.1	2.85	20
22 March 1981	3	623	2.5 - 3.4	2.87	50
26 March 1981	1	126	2.3 - 2.7	2.51	20
26 March 1981	1	181	2.7 - 3.5	3.09	20
29 March 1981	1	70	2.4 - 2.7	2.56	20

11 April almost all clusters had totally hatched, and by 18 April all had hatched.

Relatively detailed data on hatching are available for two single-spawn clusters. On 7 March 1981, a pair of *C. bairdi* and eight eggs were found under a brick and we assumed the fish were spawning. No eggs were found here on 27 February. On 14 March, what we assumed to be the remainder (and much larger portion) of that cluster was found nearby on the brick. (Lifting of the brick on 7 March presumably interrupted spawning and caused its resumption at another point.) On 22 March, eggs of the group of eight contained well-developed embryos. On 26 March, well-developed young were still visible, with earlier-stage young in the larger portion. On 29 March, the eight eggs were missing and we presume they hatched. The incubation period was thus some 22 days. The remainder had not hatched by 5 April. The brick with eggs and guarding male were then placed in a plastic gallon jar with netting at each end to allow passage of a current of water, and replaced in the stream. On 11 April, most eggs and hatchlings had decayed, but three eggs were near hatching. The development period of these eggs was thus about 35 days. About half the eggs of another cluster found on 7 March 1981 (not present on 27 February) was hatched by 5 April, and the remainder contained well-developed embryos. On 11 April only 10 eggs remained, and on 18 April there was none. Time to hatching was some 29 to 42 days.

As in the field, eggs of a cluster also hatch over a period of days in the laboratory. A field-collected cluster maintained at approximately field water temperatures (10° to 12° C) hatched as follows: 7-8 April, 4; late 8 April, 59; 9 April, 14; evening of 9 April to mid-afternoon on 12 April, several; by mid-afternoon on 13 April, 4. Three eggs from another cluster hatched on 8 April 1981.

A male guards each cluster, and a male guarding a multiple-spawn cluster was presumably successful in spawning with up to three females. Koster (1936) stated that a successful male spawns with one or more females, and Scott and Crossman (1973) noted that it is usual for more than one female to deposit eggs in a male's nest. The same male stays with a given cluster until the last eggs hatch. He is usually hidden under the egg-deposition site, but sometimes lies with the head or body exposed. Rarely a guarding male was found with a second male, and once two males were hidden with a female heavy with eggs. These latter occurrences, however, may have been sampling artifacts.

Early in the 1981 reproductive season, from 22 February through 7 March, each male examined was in dark reproductive coloration. The dorsum and sides were olive-drab to blackish, the head and fins blackish, and the first dorsal fin edged with dull yellow and orange. The posterior venter was smoky-gray with fine black stippling, and the breast and abdomen dull whitish. The normally prominent black saddles were indistinct. On 14 March, seven of eight males were so colored, while one had the more typical tan background color with prominent chocolate-brown saddles. On each subsequent date, through 29 March 1981, some males had the dark coloration described above, but the number of such males then found per date never exceeded those with the brown body. Even some males guarding eggs on and after 14 March 1981 were brown.

Water temperature during the spawning period ranged from 7.5° to 12.5° C in March 1975, and from 6.5° to 11.0° C in March 1980. Temperatures from other years were within these ranges. Koster (1937) reported spawning in upper New York State at 10° C, Bailey (1952) in Montana at 7.8° to 12.8° C, Ludwig and Norden (1969) in Wisconsin at 8.9° to 13.9° C, and Nagel (1980) in Tennessee at 12° C and 14° C. Water temperature fluctuates considerably during egg development. Temperatures (° C) at Butler Mill Branch in 1981, from the date before the first eggs were found (22 February) through the date after the last were found (18 April), were: 10.0, 9.0, 7.5, 8.0, 7.0, 11.0, 11.5, 13.5, 12.0, and 16.0. Eggs in 1980 (two dates) were found at 8.0° C and 6.5° C.

The difference between number of males (69) and females (156) collected during the reproductive season was highly significant (chi-square, $P<0.001$, expected ratio 1:1). The observed values may be a sampling artifact. However, as a male is known to spawn with more than one female, it is also possible that the observed values reflect a real difference. Ludwig and Norden (1969) noted a reduction in number of males at commencement of the spawning season, and suggested it resulted from competition for nesting sites and some segregation of sexes. Koster (1936) found no significant difference in the proportion of males to females.

Age and Growth

The Butler Mill Branch sculpins are more short-lived than reported for any other *Cottus* species. This may be related to early onset of sexual maturity. Further, only few Butler Mill Branch *C. bairdi* that reach age group I survive to spawn twice. Length-frequency distributions based on the total sample through 1980 indicate the existence of three age groups: O, I, and a presumed II (Figs. 4,5). In 1974, group I fish were present from January to September, but none was collected in November. Of later samples, some group I fish were still present in November 1978. A few may have survived the winter, as indicated by the large specimens ($\geq$ 50 mm SL) collected in March and July 1979, which would then have been in age group II. Fish corresponding to this age group were also present in the 1980 samples. Of the 403 sculpins collected in 1980, 262 (65.0%) were

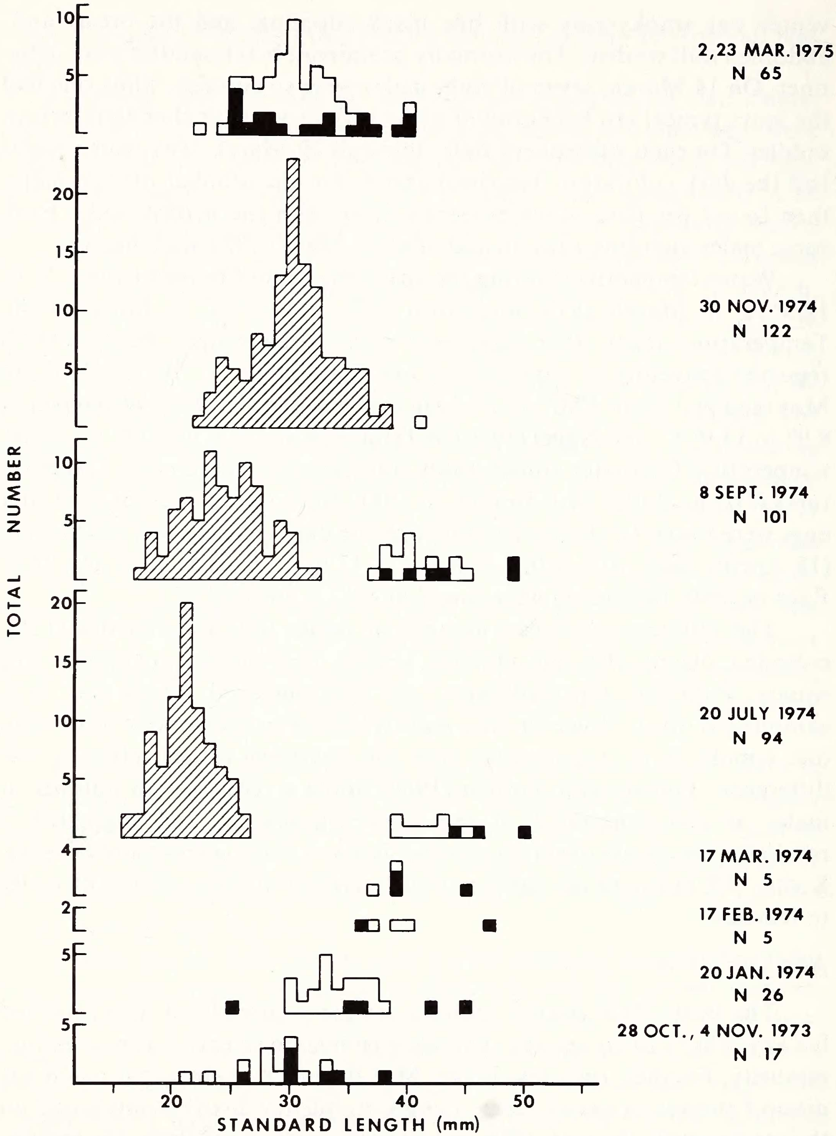

Fig. 4. Length frequencies of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, October 1973-March 1975. Solid bars = males; open bars = females; hatched bars = unsexed young.

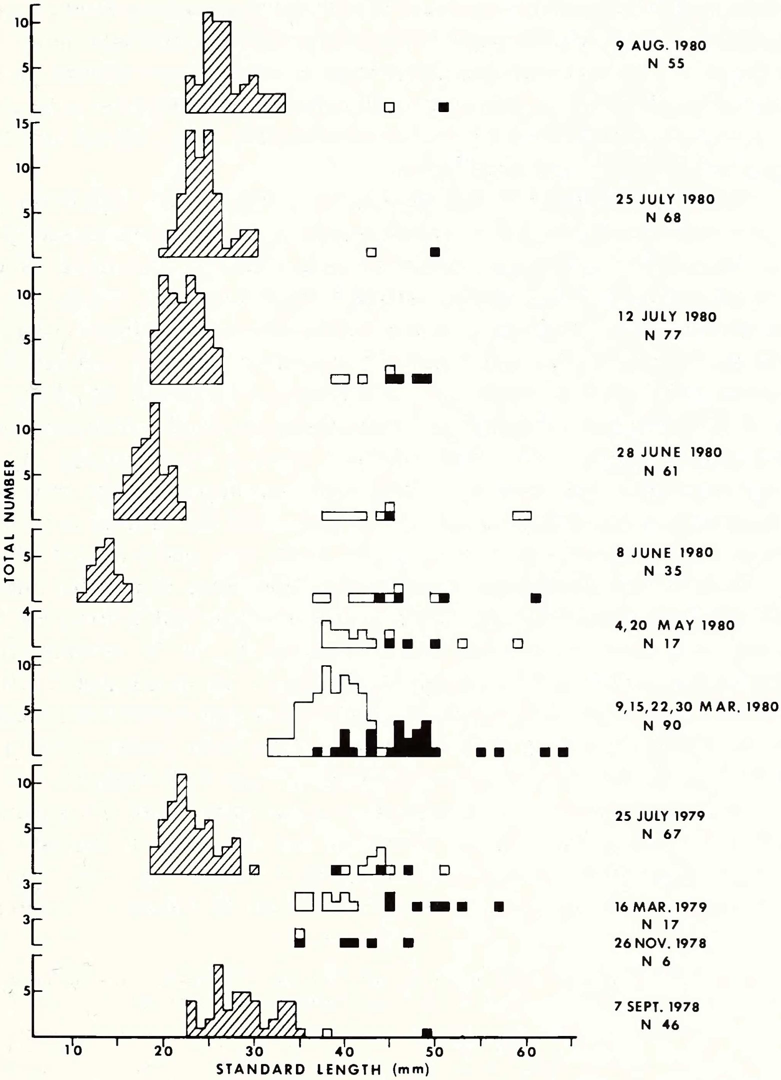

Fig. 5. Length frequencies of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, September 1978-August 1980. Solid bars = males; open bars = females; hatched bars = unsexed young.

in age group O at time of capture, 133 (33.0%) in group I, and 8 (2.0%) in presumed group II. Although the data are limited, and assuming that each age group was collected proportional to its actual number in the population, 33.0% of group 0 survived to spawn as group I fish, and 2.0% to spawn a second time. Survival rates have not been calculated for other populations of any species of *Cottus*.

Three just-hatched young (measured to nearest 0.1 mm) from one cluster averaged 6.56 mm SL, and 24 from a second cluster averaged 6.05 mm. Hann (1927) observed a mean size at hatching of 6.4 mm SL. Newly hatched young in other studies ranged from 5.6 mm SL to 9.8 mm TL (see Nagel 1980). The body of a newly hatched young is slightly opaque, with no evidence of the dark saddles, and with a prominent yolk sac. Five siblings of 98 hours of the second cluster averaged 6.54 mm SL. The yolk sac of these is greatly reduced and only slightly protrudes from the body, and melanophores form weakly-defined saddles. Five siblings of 195 hours averaged 6.96 mm SL. Their yolk sac appears fully resorbed, melanophores are conspicuous on the body, and the saddles are better defined. Three additional siblings of 288 hours averaged 6.63 mm SL.

Two young-of-year taken on 19 May 1981 were 10 mm SL and 12 mm SL, and resembled the adult in morphology and coloration. No young were taken until 8 June in 1980 (Table 4, Fig. 5), at which time they averaged 13.5 mm SL (range 11-16 mm), an assumed post-hatching increase of 7.5 mm. Subsequent samples taken approximately biweekly revealed a decrease in growth rate, from a 4.9 mm increase over 20 days to 28 June, to but a 2.4 mm increase in the 15 days to 9 August.

Most growth occurred in the first calendar year of life. Young taken in July 1974 ranged from 16 to 26 mm SL ($\bar{x}$ = 21.1 mm). From hatching at 6 mm in early to mid-April, growth in the 1974 year class was rapid: to 21.1 mm in July, 24.2 mm in September, and 30.0 mm in November

Table 4. Monthly mean standard lengths, by sex, for 1978, 1979, and 1980 year classes of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware. Number of specimens in parentheses.

	1978 Year Class			1979 Year Class			1980 Year Class
Date	Unsexed	Male	Female	Unsexed	Male	Female	Unsexed
7 Sept. 1978	30.9 (19)	-	-				
16 Mar. 1979	-	49.9 (7)	37.8 (10)				
25 Jul. 1979	-	43.3 (3)	44.0 (8)	23.1 (56)	-	-	
9, 15, 22, 30, Mar. 1980	-	59.4 (4)	-	-	45.0 (24)	38.2 (62)	-
4, 20 May 1980	-	-	59 (1)	-	47.3 (3)	41.4 (13)	-
8 Jun. 1980	-	61 (1)	-	-	47.0 (3)	42.8 (8)	13.5 (23)
28 Jun. 1980	-	-	59.5 (2)	-	45 (1)	41.3 (7)	18.4 (51)
12 Jul. 1980	-	-	-	-	47.0 (4)	41.5 (4)	22.2 (69)
25 Jul. 1980	-	-	-	-	50 (1)	43 (1)	24.5 (66)
9 Aug. 1980	-	-	-	-	51 (1)	45 (1)	26.9 (53)

Table 5. Monthly mean standard lengths, by sex, for 1973 and 1974 year classes of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware. Number of specimens in parentheses.

Date	1973 Year Class		1974 Year Class		
	Male	Female	Unsexed	Male	Female
28 Oct., 4 Nov. 1973	32.5 (6)	27.7 (10)			
20 Jan. 1974	36.6 (5)	33.8 (21)			
17 Feb. 1974	41.5 (2)	38.7 (3)			
17 Mar. 1974	41.0 (3)	38.0 (2)			
20 Jul. 1974	46.7 (3)	41.5 (8)	21.1 (83)	-	-
8 Sep. 1974	43.5 (6)	40.5 (13)	24.2 (82)	-	-
30 Nov. 1974	-	41 (1)	30.0 (121)	-	-
2 Mar. 1975	-	-	-	30.7 (18)	29.8 (37)
23 Mar. 1975	-	-	-	35.0 (3)	30.4 (7)

(Table 5). By next March these fish, now in age group I, were mature and had spawned. Males (N = 21) now averaged 31.3 mm SL and females (N = 44) 29.9 mm.

Growth in the 1973 year class was at first similar, with a combined October-November sample mean length of 29.5 mm SL. However, growth did not decrease pronouncedly or cease in winter as noted in the 1974 year class and as reported for a population by Bailey (1952). Rather, sculpins of the 1973 year class apparently continued to grow from November to March. For combined February-March 1974 samples, both sexes (5 males, 5 females) averaged some 10 mm longer than those taken in early March 1975. The reason for this difference is not known; it may be an artifact of small sample size. Nagel (1980) also noted such between-year variation in growth rate. The 1979 year class (age group I) exhibited little growth, if any, from June through August (Table 4). A few fish presumed of the 1978 year class (age group II) were also present in the 1980 samples. These were 10 to 15 mm longer than those collected the previous spring, interpreted as growth continuing during the second year of life.

Cottus bairdi in Montana exhibited a growth rate comparable to Butler Mill Branch specimens during age group 0, but none matured until in age group II and when usually longer than 74 mm TL (Bailey 1952). Ludwig and Norden (1969) observed growth similar to Sussex County *Cottus* in age groups 0 to II, but reported earliest maturity in Wisconsin sculpins in age group II ($\bar{x}$ SL = 54.5 mm, range 37-70). Nagel (1980) noted reproduction in Tennessee at the end of the second year of life, at

50-81 mm TL. Hann (1927) stated that sexual maturity in Michigan is attained by two years of age, at 45-70 mm SL. Koster (1936) found that first spawning in a stream-dwelling population near Ithaca, New York, occurred at the end of the second year of life (age group II), while some specimens of a lake-dwelling population from nearby Cayuga Lake apparently matured at the end of the first year of life (age group I). This early maturity may result from a genetic or an environmental difference between these populations.

Butler Mill Branch sculpins reached sexual maturity at a smaller size than any other population of *C. bairdi* ($\bar{x}$ SL = 37.4 mm, range 22-64, N = 225). Mean length of 33 Butler Mill Branch adults taken in 1981 was 44.7 mm SL (range 35-65 mm). Adults from the new localities in Caroline and Dorchester counties, Maryland, were of similar size ($\bar{x}$ SL = 38.7 mm, range 29-62, N = 48), and Franz and Lee (1976) noted small size in the other Caroline County population.

Mature males in the March and May 1978-80 samples were larger ($\bar{x}$ SL = 47.6 mm, range 37-64, N = 38) than mature females ($\bar{x}$ SL = 38.9 mm, range 32-59, N = 86), a highly significant difference ($P<0.001$). However, there was no significant difference at the 0.05 level in the January, February, and March 1973-75 samples (mature males, $\bar{x}$ SL = 33.7 mm, range 25-47, N = 31; mature females, $\bar{x}$ SL = 31.7 mm, range 22-40, N = 70). The reason for the size difference of 1978-80 is not apparent. Such sexual dimorphism was also observed by Hann (1927), Bailey (1952), Ludwig and Norden (1969), and Nagel (1980), but not in New York sculpins by Koster (1937).

Regressions for the weight-length relationship derived for males and females from both sampling periods are: (1973-75) males, Log W = - 10.8985 + 3.0585 Log L, r = 0.99; females, Log W = -10.3999 + 2.8814 Log L, r = 0.99; (1978-80) males, Log W = -11.8313 + 3.3681 Log L, r = 0.99; and females, Log W = -11.0505 + 3.1412 Log L, r = 0.99. Analysis of covariance reveals significant differences ($P<0.05$) in slope between sexes and between years. A slope greater than 3.00, indicating that relative weight increased faster than length (Ricker 1971), is noted in three of four regressions. Only females in 1973-75 showed a slightly faster increase in length when compared to weight.

There is a strong, and expected, positive correlation between SL and TL: SL = 1.21 + 0.76 TL, r = 0.93.

Condition factor (K) for both sexes is lowest during the coldwater months preceding spawning (Table 6). Highest K values were recorded during the warmwater period subsequent to spawning. With the exceptions of October and November, males were more robust than females.

Table 6. Combined monthly averages of coefficient of condition (K) for male and female *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, 1973-1980. Male N = 145, female N = 278.

Month	Male		Female	
	Gonads in situ	Gonads excised	Gonads in situ	Gonads excised
Jan.	2.06	2.06	2.06	1.93
Feb.	2.10	2.08	2.44	1.96
Mar.	2.88	2.84	2.58	2.12
May	3.07	3.07	2.63	2.62
Jun.	2.88	2.88	2.67	2.65
Jul.	2.53	2.70	2.27	2.26
Aug.	3.33	3.33	2.68	2.66
Sep.	2.36	2.26	2.14	2.06
Oct.	2.19	2.17	2.20	2.17
Nov.	2.34	2.32	2.39	2.34

Food Habits

Based on stomach contents of 539 fish (12-64 mm SL), food is primarily larval trichopterans (in 55.7% of stomachs) and dipterans (42.3%), and plecopteran nymphs (19.7%); less important are crustaceans (9.2%), ephemeropteran nymphs (8.0%), and coleopteran larvae (2.4%) (Table 7). Nineteen taxa were identified. One hundred and twenty-eight (23.7%) stomachs were empty. Franz and Lee (1976) found 5 taxa in 10 specimens. Ricker (1934), Koster (1936, 1937), Dineen (1951), Bailey (1952), and Daiber (1956) also found that the primary food was benthic insect larvae.

Seasonal variation in diet is evident (Table 7). Trichopterans, mainly Hydropsychidae, were eaten in all months except February, and were dominant in March, July, August, and September. Dipterans, primarily Chironomidae, were the most common food in January, June, October, and November. Plecopterans were common from January through May.

Prey taxa differed only slightly by fish size group (Table 8). Chironomids were relatively more important to sculpins smaller than 19 mm SL than to longer fish. Larger specimens (>49 mm SL) ate fewer chironomids but more larger simulids. A 43 mm SL sculpin contained one 25 mm SL *Etheostoma olmstedi*, and a 53 mm SL specimen had eaten an egg of *Lampetra aepyptera*.

Table 7. Percent frequency of occurrence, by month, of food items in *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, 1973-1980.

Food	Jan.	Feb.	Mar.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Total
Nematoda					2.7					2.2	0.5
Oligochaeta			1.8							2.2	0.7
Crustacea											9.2
Amphipoda			7.0		18.9	10.8	35.3			2.2	
Isopoda						1.2					
Insecta											
Plecoptera											19.7
Perlodidae			31.6	53.8						2.2	
Chloroperlidae			6.1							2.2	
Unidentified	20.0	20.0	17.5			1.2				4.4	
Ephemeroptera											8.0
Heptageniidae			13.2		2.7	2.4	5.9			2.2	
Leptophlebiidae	5.0					1.2		2.0	9.1	2.2	
Unidentified	10.0					2.4		4.1		2.2	
Odonata											0.7
Anisoptera	5.0							2.0			
Zygoptera		10.0									
Trichoptera											55.7
Hydropsychidae	10.0		58.8	46.2	45.9	74.7	35.3	77.6	45.4	26.7	
Phryganeidae								2.0			
Unidentified	20.0		13.2								

Coleoptera											2.4
Elmidae	10.0	10.0	2.6					2.0			
Gyrinidae			0.9								
Unidentified	10.0										
Diptera											42.3
Chironomidae	85.0	10.0	12.3	23.1	48.9	32.5	29.4	26.5	72.7	84.4	
Simuliidae			6.1			4.8		4.1	18.2		
Tipulidae			3.5								
Unidentified										2.2	
Insect Remains	15.0	20.0	14.0	7.7	13.5	12.0	8.8	14.3	45.4	20.0	15.1
Osteichthyes											0.5
Lampetra aepyptera				7.7							
Etheostoma olmstedi								2.0			
Plant Material	5.0										0.2
Unidentified Debris	25.0	20.0								2.2	1.9
Sand Grains	15.0		7.9		16.2	2.4	20.6	4.1		6.7	12.6
Number Empty	6	0	39	4	3	37	21	11	0	7	128
Number Examined	26	5	153	17	40	120	55	60	11	52	539

Table 8. Mean number of food items, by length groups, in stomachs of *Cottus bairdi* from Butler Mill Branch, Sussex County, Delaware, 1973-1980.

Food	*Cottus* SL (mm)				
	<20	20-29	30-39	40-49	>49
Nematoda			.01	.04	
Oligochaeta			.01	.01	
Crustacea					
Amphipoda	.22	.15	.04	.16	.08
Isopoda		.01			
Insecta					
Plecoptera					
Perlodidae		.01	.36	.53	.15
Chloroperlidae			.03	.04	
Unidentified		.13	.15	.06	
Ephemeroptera					
Heptageniidae	.06	.04	.10	.06	.08
Leptophlebiidae		.02	.02		
Unidentified		.02	.02	.01	
Odonata					
Anisoptera			.01		
Zygoptera				.01	
Trichoptera					
Hydropsychidae	1.17	.89	.94	1.16	1.23
Phryganeidae		.01			
Unidentified		.09	.19	.04	
Coleoptera					
Elmidae		.01	.06	.01	
Gyrinidae		.01			
Unidentified			.01		
Diptera					
Chironomidae	7.89	1.61	2.51	.28	.23
Simuliidae		.10	.05	.19	.46
Tipulidae			.03		
Unidentified		.01			
Osteichthyes					
Lampetra aepyptera					.08
Etheostoma olmstedi				.01	
Number of stomachs with countable food items	18	122	152	68	13

Abundance

Throughout most of this study we assumed that the Butler Mill Branch sculpin population was small. Work in early 1980, however, revealed the species to be more widely distributed here than previously known, and in March both frequency of sampling and sample size were increased. Surprisingly, no effect of increased collecting on the population was noted. Although on each collection date the sampling area was almost cleared of specimens, and no additional sculpin could be found, on each subsequent visit the area again was productive. Thus, it appears that many fish escaped capture, or that there was extensive and rapid movement into the sampling area from nearby. Probably both were important. Certainly larval *C. bairdi* are secretive, which probably explains our failure to catch them at Butler Mill Branch. Hatchlings in the laboratory are benthic to at least 288 hours. When disturbed they are strong swimmers, but then settle rapidly and remain quietly in gravel. This larva-gravel association may explain why *C. bairdi* is restricted to areas of gravel.

Further, lower Butler Mill Branch, including all of the sampling area, was poisoned with rotenone in May 1976 by Delaware Division of Fish and Wildlife personnel to foster game fish in Craigs Pond (Roy W. Miller, pers. comm.). Sampling for sculpins in 1978 revealed no effect of the rotenoning. We conclude that the population of *C. bairdi* here is healthy, and the adjacent Maryland populations also appear to be strong.

ACKNOWLEDGMENTS.— We thank the following individuals for their help. Johnson C.S. Wang, Nancy J. Bieber, Ruth A. Hermansen, Judith K. Heyman, Michael J. Hozik, Joan A. Pienta, and several Stockton State College students assisted in collecting. J.C.S. Wang also examined sculpin eggs, and Michael J. Hozik provided information on geology. Robert H. Simmons, U.S.D.I. Geological Survey, Water Resources Division, Dover, Delaware, provided stream flow data. Roy W. Miller, Supervisor of Finfisheries, Delaware Division of Fish and Game, Dover, supplied information on rotenoning in Butler Mill Branch. William L. Pflieger, Missouri Department of Conservation, Columbia, provided information on the Ozark populations of *C. bairdi*. Robbin N. Rogers searched samples for fish eggs and larvae. Bruce W. Menzel and Steve W. Ross made numerous helpful comments during manuscript preparation. Nancy J. Bieber and Deborah K. Wozniak typed drafts of the manuscript. John E. Cooper and an anonymous reviewer provided helpful comments during manuscript review.

LITERATURE CITED

Bailey, Jack E. 1952. Life history and ecology of the sculpin *Cottus bairdi punctulatus* in southwestern Montana. Copeia 1952(4):243-255.

Daiber, Franklin C. 1956. A comparative analysis of the winter feeding habits of two benthic stream fishes. Copeia 1956 (3): 141-151.

Dineen, Clarence F. 1951. A comparative study of the food habits of *Cottus bairdi* and associated species of Salmonidae. Am. Midl. Nat. *46*(3): 640-645.

Foltz, Jeffrey W. 1976. Fecundity of the slimy sculpin, *Cottus cognatus*, in Lake Michigan. Copeia 1976*(4)*:802-804.

Franz, Richard, and D.S. Lee. 1976. A relict population of the mottled sculpin, *Cottus bairdi*, from the Maryland Coastal Plain. Chesapeake Sci. *17*(4):301-302.

Gage, Simon H. 1878. Notes on the Cayuga Lake star gazer. Cornell Rev. *6*(2):91-94.

Hann, Harry W. 1927. The life history of the germ cells of *Cottus bairdi* Girard. J. Morphol. Physiol. *43*(2):427-497.

Hoar, W.S. 1957. The gonads and reproduction. pp. 287-317 *in* M.E. Brown (ed.). The Physiology of Fishes, Vol. I. Academic Press, Inc., New York. 465 pp.

Koster, William J. 1936. The life-history and ecology of the sculpins (Cottidae) of central New York. Unpubl. Ph.D. dissert., Cornell Univ., Ithaca. 87 pp. + Appendix and figures.

______ . 1937. The food of sculpins (Cottidae) in central New York. Trans. Am. Fish. Soc. *66*:374-382.

Lee, David S. 1980. *Cottus bairdi* Girard. Mottled sculpin. p. 805 *in* D.S. Lee et al. Atlas of North American Freshwater Fishes. N.C. State Mus. Nat. Hist., Raleigh. x + 867 pp.

Ludwig, Gerald M., and C.R. Norden. 1969. Age, growth and reproduction of the northern mottled sculpin (*Cottus b. bairdi*) in Mt. Vernon Creek, Wisconsin. Milw. Public Mus. Occas. Pap. Nat. Hist. 2:1-67.

Nagel, Jerry W. 1980. Life history of the mottled sculpin, *Cottus bairdi*, in northeastern Tennessee (Osteichthyes: Cottidae). Brimleyana 4:115-121.

Patten, Benjamin G. 1971. Spawning and fecundity of seven species of northwest American *Cottus*. Am. Midl. Nat. *85*(2):493-506.

Petrosky, Charles E., and T.F. Waters. 1975. Annual production by the slimy sculpin population in a small Minnesota trout stream. Trans. Am. Fish. Soc. *104*(2):237-244.

Pflieger, William L. 1975. The Fishes of Missouri. Mo. Dep. Conserv., Jefferson City. 343 pp.

Ricker, William E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud. Biol. Ser. No. 37. 114 pp.

______ . 1971. Methods for assessment of fish production in fresh waters. 2nd ed. IBP Handbook No. 3. Blackwell Sci. Publ., Oxford. 348 pp.

Robins, C. Richard. 1954. A taxonomic revision of the *Cottus bairdi* and *Cottus carolinae* species groups in eastern North America (Pisces, Cottidae). Unpubl. Ph.D. dissert., Cornell Univ., Ithaca. 248 pp.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.

Smith, Bertram G. 1922. Notes on the nesting habits of *Cottus*. Pap. Mich. Acad. Sci. Arts Lett. *2*:222-224.

Williams, James D. 1968. A new species of sculpin, *Cottus pygmaeus*, from a spring in the Alabama River Basin. Copeia 1968(2):334-342.

Accepted 28 December 1981